CAAP Quarterly Report

Date of Report: *March 31, 2020*

Contract Number: 693JK31950005CAAP

Prepared for: *USDOT Pipeline and Hazardous Materials Safety Administration (PHMSA)*

Project Title: *An Unmanned Aerial System of Visible Light, Infrared and Hyperspectral Cameras with Novel Signal Processing and Data Analytics*

Prepared by: *Missouri University of Science and Technology (Missouri S&T)*

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For quarterly period ending: *March 31, 2020*

Business and Activity Section

(a) General Commitments – Dr. Genda Chen directed the entire project and coordinated various project activities.

Dr. Bo Shang, a post doc at Missouri S&T, joined the research team in February of 2020. Dr. Shang is responsible for the hardware and software integration of visible light, infrared and hyperspectral cameras and associated validation tests under Dr. Chen's supervision. Mr. Pengfei Ma, a Ph.D. student in civil engineering at Missouri S&T, was on board since November 15, 2019. Mr. Ma is responsible for the laboratory and field tests of an integrated system of visible light, infrared and hyperspectral cameras and for image analysis under Drs. Chen and Shang's supervision. Mr. Jiao Pu, another Ph.D. student in civil engineering at Missouri S&T, was on board since October 1, 2019. As needed, Mr. Pu is responsible for the finite element model of an unmanned aerial system with cameras.

(b) Status Update of Past Quarter Activities – Detailed updates are provided below by task.

This project aims to:
1. Develop and integrate a robust and stable, semi- or fully-automated UAS with multiple sensors for multi-purpose pipeline safety data collection,
2. Explore and develop novel signal and image processing techniques for data analytics, damage assessment, and condition classification, and
3. Evaluate and validate field performance of the integrated UAS for pipeline safety inspection.

These objectives will be achieved through analytical, numerical, and experimental investigations in three tasks:
1 To design and prototype the UAS for the collection of cohesive types of images from visible light, infrared, and hyperspectral cameras, and demonstrate the potential of the collected images for the evaluation of ground conditions and pipeline risks for decision makers;
2 To develop and validate one-dimensional (1D) spectral analysis at each pixel of a hyperspectral image, two-dimensional (2D) image classification of changes, spatial analysis of a hyperspectral image and its fusion with other images for increased probability of detection, and three-dimensional (3D) object establishment for volume estimates; and
3 To develop a physically-interpretable, deep learning neural network for the selection of images (frames) with regions of interest from long hours of video footage, recorded as the unmanned

vehicle flies along a pipeline, and demonstrate in field conditions the UAS performance in the assessment of pipeline and surrounding conditions, population-impacted changes, above-ground objects, accident responses, and mapping system accuracy.

Task 1 Design of the integrated UAS for the collection of image data and demonstration of the potential to evaluate ground conditions

1a Design of the integrated UAS

A Duo Pro R640 camera (FLIR) and a VNIR hyperspectral camera (Headwall) are under procurement. Due to the COVID-19, major acquisitions are on hold at Missouri S&T.

Once received, they will be integrated into an unmanned aerial system (UAS). The Duo Pro R640 camera includes a visible Len and an infrared Len arranged in parallel. The infrared Len can be used to take a thermographic image based on thermal radiation, and the visible Len is for a photographic image based on visible light reflection. The infrared camera has a measurement accuracy of ±5 °C or 5% of readings between -25°C and +135°C, and a thermal sensor resolution of 640 × 512 in space. The hyperspectral camera equips conventional spectroscopy with the capability of spatial/spectral information acquisition based on light reflection from a surface, greatly enhancing abnormality detection abilities and extending application scopes. The hyperspectral image has a sensor spatial and spectral resolution of 640 and 271 pixels, respectively. Unlike remote sensing via satellites, rapid improvements in camera resolution and stabilizer can further enhance video clarity and details particularly from close views obtained via a UAS.

1b Demonstration of the capability of UAS in laboratory and field tests

The aim of developing the integrated UAS is to facilitate data collection in field applications for the detection of oil leakages and evaluation of ground conditions. Both laboratory and field tests will be designed and conducted in this task.

Parallel to the design of the integrated UAS, a conceptual design of laboratory tests is beginning. To fully validate and realize the potential of the UAS system, such tests should include a variety of elements in two categories: underground (Fig.1) and aboveground (Fig.2). The elements considered herein are based on their relevance to hyperspectral and thermal imaging, and various companies' pipeline profiles in order to make the hyperspectral and infrared cameras work collaboratively and test the full capability and applicability of the cameras. Disturbances are also included in the capacity validation of the UAS to maintain acceptable robustness when collecting data in various working ambiences.

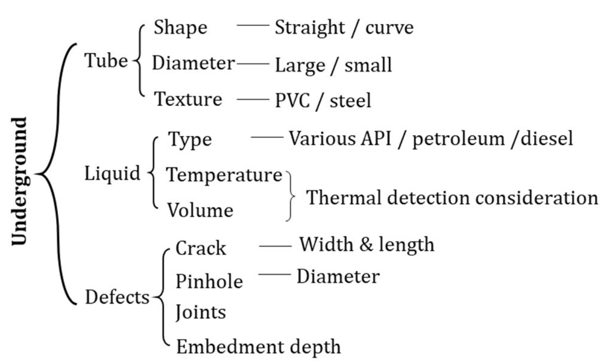

Fig. 1 Underground pipeline factors

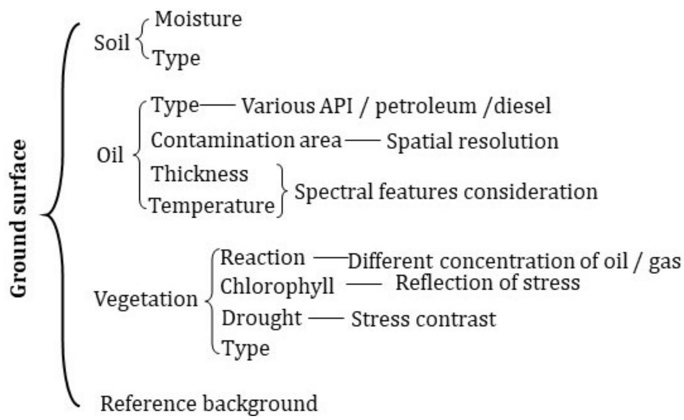

Fig. 2 Ground surface factors

As shown in Fig. 1, a set of underground pipeline factors are specially designed for thermal camera based on its functionality because it can scan through objects to determine the condition of underground pipelines as a decision-making tool. As shown in Fig. 2, a set of ground surface factors are more customized for hyperspectral cameras that can obtain the spectral features of different materials: oil, soil, and vegetation for leakage detection. Additionally, the thermal camera can obtain thermal image of materials on the ground surface to cooperate with the hyperspectral camera for data fusion, thus enhancing the detectability of various scenarios. Equally if not more important, these factors must be prioritized and divided into dominant and secondary groups to steer concentrated efforts on pipeline leakage detection.

Table 1. Summary of Important Factors

Dominant Factors		**Secondary Factors**	
Underground	Ground surface	Underground	Ground surface
Embedment depth	Soil type	Tube parameters	Chlorophyll content
Liquid temperature	Oil type	Cracks	Reference
Liquid volume	Contamination area	Pinholes	
	Slick thickness	Joint rupture	
	Vegetation type		
	Drought / oil / gas affected		

To simulate the designed factors in laboratory tests with the purpose of validating the capability of both hyperspectral and infrared cameras, it is quite necessary to contrive a test bed in the laboratory to collect data of different scenarios. An example test bed of this type proposed by the University of Alberta is displayed in Fig.3.

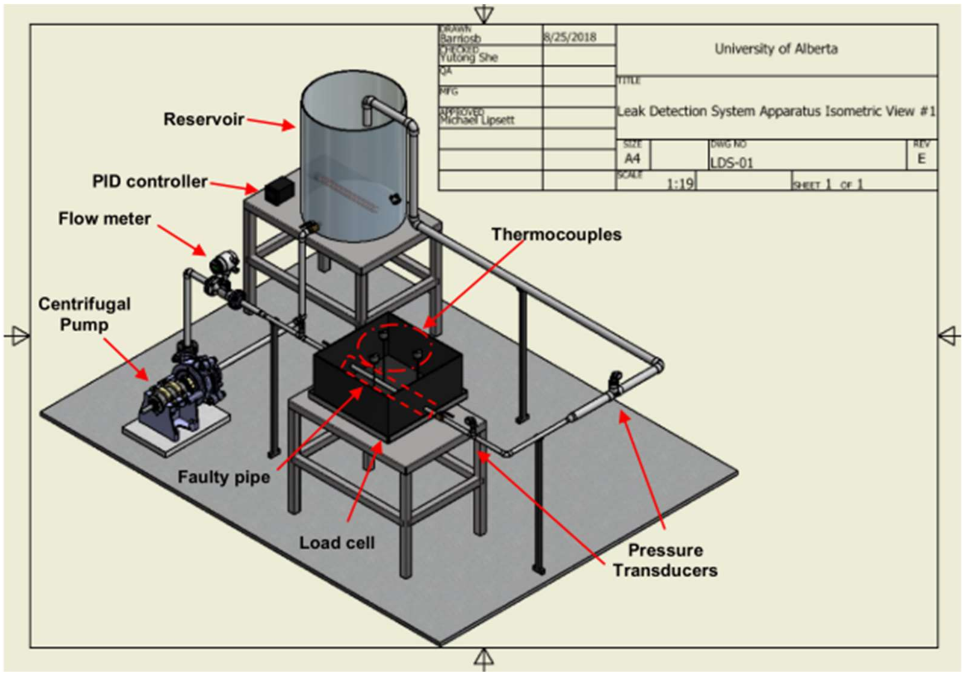

Fig. 3 An example test bed by the University of Alberta

The workflow for laboratory test plan, design and execution is presented in Fig. 4. It includes a satisfaction check on the detailed design after a flexibility analysis is completed. This workflow also directs how to organize the test beforehand.

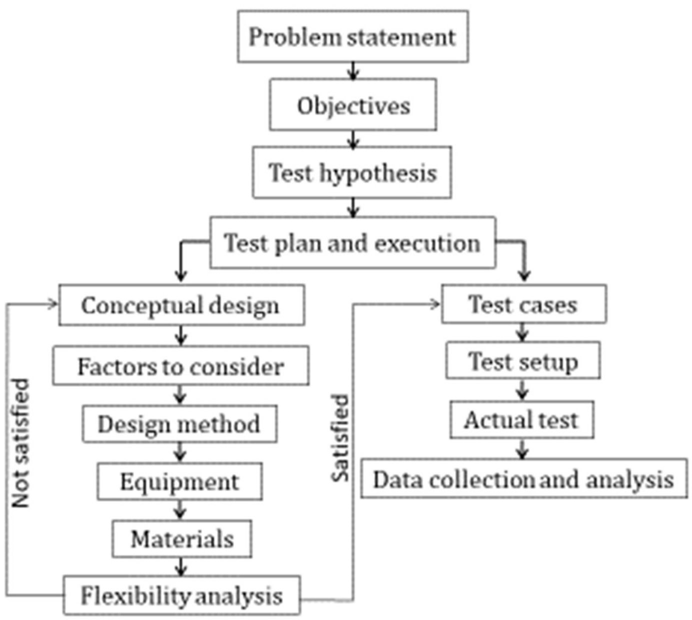

Fig. 4 Workflow of laboratory test plan and execution

Task 2. Develop and validate 1D spectral analysis at each pixel of a hyperspectral image, 2D image classification of changes, spatial analysis of a hyperspectral image and its fusion with others for increased probability of detection, and 3D object establishment for volume estimates.

Literature reviews continued to understand the latest development in pipeline condition inspection and assessment with remote sensing. In particular, one-dimensional (1D) spectral analysis at each pixel of a hyperspectral image began with the extended 1D adaptive wavelet transform to understand its general behavior.

Task 3. Develop a physically-interpretable neural network for the selection of images (frames) from video footage and demonstrate in field conditions the UAS in the assessment of pipeline and surrounding conditions, population-impacted changes, above-ground objects, accident responses, and mapping system accuracy.

This task will not start till the 4th quarter in 2020.

(c) Planned Activities for the Next Quarter - The following activities will be executed during the next reporting quarter.

Task 1. Design and prototype the UAS for the collection of images from visible light, infrared, and hyperspectral cameras, and demonstrate the potential of the collected images for the evaluation of ground conditions and pipeline risks for decision makers.

To continue to procure the hyperspectral and infrared cameras and integrate them into a UAS. Determine the final factors to include in the laboratory test and develop a thorough test plan. Have all necessary equipment, materials, space, and staff in place to fully prepare for laboratory tests and collect data for Task 2.

Task 2. Develop and validate 1D spectral analysis at each pixel of a hyperspectral image, 2D image classification of changes, spatial analysis of a hyperspectral image and its fusion with others for increased probability of detection, and 3D object establishment for volume estimates.

The 1D adaptive wavelet transform will be applied to extract the ground and material conditions along a pipeline through the abnormalities in space, which are represented by the changes in wavenumber. The effectiveness of the extended transform will be investigated using the data obtained in Task 1 from laboratory tests, once available.

(d) Problems Encountered during this Quarter and Potential Impact on Next Quarter – This project has been impacted by the COVID-19. At Missouri S&T, laboratories were closed to students on March 16, 2020. Since then, all experimental works stopped. Even computer access may become an issue due to high traffic on internet during the period of virus spread, which will impact any computationally intensive tasks that require special computers from a remote site. Both the laboratory and computer access issues will likely continue to the first part or most part of the summer semester, which will impact the progress during the next reporting period.